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# UTILITY PATENT APPLICATION TRANSMITTAL

(Only for new nonprovisional applications under 37 CFR 1.53(b))

Attorney Docket No.	NO070 US
First Inventor	HUBER
Title	Multi-Dimensional Spatial Index for a Geographic Database
Express Mail Label No.	EF173000857US

## APPLICATION ELEMENTS

See MPEP chapter 600 concerning utility patent application contents

- ☒ Fee Transmittal Form (e.g., PTO/SB/17)  
(Submit an original and a duplicate for fee processing)
- ☐ Applicant claims small entity status.  
See 37 CFR 1.27.
- ☒ Specification [Total Pages 18]  
(preferred arrangement set forth below)
  - Descriptive title of the invention
  - Cross Reference to Related Applications
  - Statement Regarding Fed sponsored R & D
  - Reference to sequence listing, a table, or a computer program listing appendix
  - Background of the Invention
  - Brief Summary of the Invention
  - Brief Description of the Drawings (if filed)
  - Detailed Description
  - Claim(s)
  - Abstract of the Disclosure
- ☒ Drawing(s) (35 U.S.C. 113) [Total Sheets 7]
- Oath or Declaration [Total Pages 2]
  - ☒ Newly executed (original or copy)
  - ☐ Copy from a prior application (37 CFR 1.63 (d))  
(for continuation/divisional with Box 17 completed)
    - ☐ **DELETION OF INVENTOR(S)**  
Signed statement attached deleting inventor(s) named in the prior application, see 37 CFR 1.63(d)(2) and 1.33(b)
- ☐ Application Data Sheet. See 37 CFR 1.76

ADDRESS TO: Assistant Commissioner for Patents  
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Washington, DC 20231

- ☐ CD-ROM or CD-R in duplicate, large table or Computer Program (Appendix)
- Nucleotide and/or Amino Acid Sequence Submission (if applicable, all necessary)
  - ☐ Computer Readable Form (CRF)
  - Specification Sequence Listing on:
    - ☐ CD-ROM or CD-R (2 copies); or
    - ☐ paper
  - ☐ Statements verifying identity of above copies

## ACCOMPANYING APPLICATION PARTS

- ☒ Assignment Papers (cover sheet & document(s))
- ☐ 37 CFR 3.73(b) Statement (when there is an assignee) ☐ Power of Attorney
- ☐ English Translation Document (if applicable)
- ☐ Information Disclosure Statement (IDS)/PTO-1449 ☐ Copies of IDS Citations
- ☐ Preliminary Amendment
- ☒ Return Receipt Postcard (MPEP 503) (Should be specifically itemized)
- ☐ Certified Copy of Priority Document(s) (if foreign priority is claimed)
- ☐ Other: .....

17. If a CONTINUING APPLICATION, check appropriate box, and supply the requisite information below and in a preliminary amendment, or in an Application Data Sheet under 37 CFR 1.76:

☐ Continuation ☐ Divisional ☐ Continuation-in-part (CIP) of prior application No.: \_\_\_\_\_/\_\_\_\_\_

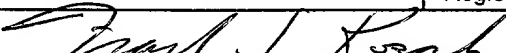
Prior application information: Examiner \_\_\_\_\_ Group / Art Unit. \_\_\_\_\_

For CONTINUATION OR DIVISIONAL APPS only: The entire disclosure of the prior application, from which an oath or declaration is supplied under Box 5b, is considered a part of the disclosure of the accompanying continuation or divisional application and is hereby incorporated by reference. The incorporation can only be relied upon when a portion has been inadvertently omitted from the submitted application parts.

## 18. CORRESPONDENCE ADDRESS

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Signature		Date	NOV 6, 2000

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**FEE TRANSMITTAL  
for FY 2001**

Patent fees are subject to annual revision.

**Complete if Known**

Application Number	
Filing Date	11/6/00
First Named Inventor	HUBER
Examiner Name	
Group Art Unit	
Attorney Docket No.	N0070US

**TOTAL AMOUNT OF PAYMENT**

(\$ 1020—

**METHOD OF PAYMENT**

- 1.
- ☒
- The Commissioner is hereby authorized to charge indicated fees and credit any overpayments to:

Deposit Account Number	50 0728
Deposit Account Name	Navigation Technologies

☒ Charge Any Additional Fee Required  
Under 37 CFR 1.16 and 1.17☐ Applicant claims small entity status.  
See 37 CFR 1.27

- 2.
- ☐
- Payment Enclosed:**

☐ Check ☐ Credit card ☐ Money Order ☐ Other**FEE CALCULATION****1. BASIC FILING FEE**

Large Entity		Small Entity		Fee Description	Fee Paid
Fee Code	Fee (\$)	Fee Code	Fee (\$)		
101	710	201	355	Utility filing fee	710
106	320	206	160	Design filing fee	
107	490	207	245	Plant filing fee	
108	710	208	355	Reissue filing fee	
114	150	214	75	Provisional filing fee	

**SUBTOTAL (1)** (\$ 710**2. EXTRA CLAIM FEES**

Total Claims		Extra Claims		Fee from below		Fee Paid	
Independent Claims	17	-20** =	0	X	—	=	—
Multiple Dependent	2	-3** =	0	X	—	=	—
						270 = 270	

Large Entity		Small Entity		Fee Description	Fee Paid
Fee Code	Fee (\$)	Fee Code	Fee (\$)		
103	18	203	9	Claims in excess of 20	
102	80	202	40	Independent claims in excess of 3	
104	270	204	135	Multiple dependent claim, if not paid	
109	80	209	40	** Reissue independent claims over original patent	
110	18	210	9	** Reissue claims in excess of 20 and over original patent	

**SUBTOTAL (2)** (\$ 270

\*\*or number previously paid, if greater; For Reissues, see above

**FEE CALCULATION (continued)****3. ADDITIONAL FEES**

Large Entity		Small Entity		Fee Description	Fee Paid
Fee Code	Fee (\$)	Fee Code	Fee (\$)		
105	130	205	65	Surcharge - late filing fee or oath	
127	50	227	25	Surcharge - late provisional filing fee or cover sheet	
139	130	139	130	Non-English specification	
147	2,520	147	2,520	For filing a request for ex parte reexamination	
112	920*	112	920*	Requesting publication of SIR prior to Examiner action	
113	1,840*	113	1,840*	Requesting publication of SIR after Examiner action	
115	110	215	55	Extension for reply within first month	
116	390	216	195	Extension for reply within second month	
117	890	217	445	Extension for reply within third month	
118	1,390	218	695	Extension for reply within fourth month	
128	1,890	228	945	Extension for reply within fifth month	
119	310	219	155	Notice of Appeal	
120	310	220	155	Filing a brief in support of an appeal	
121	270	221	135	Request for oral hearing	
138	1,510	138	1,510	Petition to institute a public use proceeding	
140	110	240	55	Petition to revive - unavoidable	
141	1,240	241	620	Petition to revive - unintentional	
142	1,240	242	620	Utility issue fee (or reissue)	
143	440	243	220	Design issue fee	
144	600	244	300	Plant issue fee	
122	130	122	130	Petitions to the Commissioner	
123	50	123	50	Petitions related to provisional applications	
126	240	126	240	Submission of Information Disclosure Stmt	
581	40	581	40	Recording each patent assignment per property (times number of properties)	40
146	710	246	355	Filing a submission after final rejection (37 CFR § 1.129(a))	
149	710	249	355	For each additional invention to be examined (37 CFR § 1.129(b))	
179	710	279	355	Request for Continued Examination (RCE)	
169	900	169	900	Request for expedited examination of a design application	

Other fee (specify) \_\_\_\_\_

\*Reduced by Basic Filing Fee Paid

**SUBTOTAL (3)** (\$ 40**SUBMITTED BY****Complete (if applicable)**

Name (Print/Type)	Frank J. Kozak	Registration No. (Attorney/Agent)	32,908	Telephone	847/795-7371
Signature	<i>Frank J. Kozak</i>	Date	Nov. 6, 2000		

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PATENT  
N0070US

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE  
APPLICATION FOR UNITED STATES LETTERS PATENT

INVENTORS:      THOMAS K. HUBER  
                     WILLIAM GALE

TITLE:            MULTI-DIMENSIONAL SPATIAL  
                     INDEX FOR A GEOGRAPHIC  
                     DATABASE

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# MULTI-DIMENSIONAL SPATIAL INDEX FOR A GEOGRAPHIC DATABASE

## BACKGROUND OF THE INVENTION

The present invention relates to geographic databases and more particularly, the present invention relates to an index that is useful for accessing and using data in geographic database.

Geographic data are used for various purposes in various different kinds of computing platforms. Geographic data are used in in-vehicle navigation systems to provide drivers of the vehicles with various useful navigation-related and map-related features. Geographic data are also used by navigation-related and map-related services on the Internet.

When using geographic data there is often a need to access the data spatially, i.e., to find data based on the locations of the geographic features represented thereby. One way to access geographic data spatially is to use a spatial index, such as a  $k$ -d-tree index. A  $k$ -d-tree index has a tree structure, having a root node, leaf nodes and intermediate nodes between the root node and the leaf nodes. Each node in a  $k$ -d-tree structure is part of a parent-child relationship. Each parent node includes control information from which one (of two or more) child nodes associated with the parent node can be distinguished based on a search key.

When a  $k$ -d-tree is used as a spatial index, the root node and intermediate nodes include two dimensional spatial boundary information (e.g., latitude and longitude) that relate to the indexed item of data. The indexed item of data can be an item of data that represents a single geographic feature. Alternatively, the indexed item of data can be a collection of data items that represent geographic features encompassed within a bounded area. As an example, a  $k$ -d-tree can be used as an index to collections (i.e., parcels) of data that represent geographic features located within separate rectangular areas. The nodes of a  $k$ -d-tree used for this purpose include the boundary information (i.e., maximum latitude, maximum longitude, minimum latitude, minimum longitude) that

1 define the separate rectangular areas that contain the geographic features represented by  
2 the data in the respective parcels.

3 A *k*-d-tree used for organizing geographic data is described in U.S. Pat. No.  
4 5,953,722, the entire disclosure of which is incorporated by reference herein.

5 When using geographic data, it is sometimes useful to access the data at different  
6 levels of detail (or granularity). Map display and route calculation are examples of two  
7 applications in which geographic data are sometimes used at different levels of detail.  
8 For example, when using geographic data with a map display application to display a  
9 map of an area, a greater level of detail is used for relatively larger scale maps and a  
10 lesser level of detail is used for relatively smaller scale maps. Similarly, when  
11 performing route calculation, it is often preferable not to consider smaller, low volume  
12 roads when determining a route between an origin and a destination.

13 In order to facilitate navigation functions that access and use geographic data at  
14 different levels of detail, data that represent geographic features are sometimes organized  
15 into layers based on a rank associated with the represented features. The lowest rank  
16 (e.g., 0) is associated with those features that are represented only when the finest level of  
17 detail is desired. In the case of roads, the lowest rank may be associated with side streets  
18 and alleys. On the other hand, the highest rank (e.g., 4) is associated with the most  
19 important features, i.e., those that would be displayed even at the coarsest level of detail.  
20 In the case of roads, the highest rank may be associated with expressways and major  
21 arterial roads.

22 When data representing geographic features are organized into layers, the lowest  
23 layer (e.g., 0) includes data representing geographic features of all ranks (e.g., 0-4). A  
24 highest layer (e.g., 4) includes data representing geographic features of only the highest  
25 rank (e.g., 4). Each other layer includes only those data that represent those geographic  
26 features of the associated rank and higher ranks. For example, layer 2 includes data that  
27 represent geographic features having ranks 2, 3 and 4. Layer 2 excludes data that  
28 represents geographic features of ranks 0 and 1. When data representing geographic  
29 features are organized into layers in this manner, a lowest layer has the greatest  
30 granularity and the highest layer has the least granularity.

These layers can exist as separate collections of the geographic data. When a navigation function requires the geographic data with a high level of detail, a lower layer is accessed and used. On the other hand, when a navigation function requires the geographic data with a low level of detail, a higher layer is accessed and used.

When data representing geographic features are organized into separate layers of granularity, a  $k$ -d-tree can be used to access the data spatially. A separate  $k$ -d-tree is used for each layer.

Figure 1 shows a database structure 100 in which the data are organized into separate layers, labeled 0, 1, and 2. Each separate layer includes a separate collection of the geographic data, with layer 0 including the data that represent geographic features ranked 0, 1 and 2, layer 1 including the data that represent the geographic features ranked 1 and 2, and layer 2 including only the data that represent the geographic features ranked 2. Each separate layer also includes its own  $k$ -d-tree indexing information. Because each lower layer includes all the items of data represented in all higher layers, many items of data that represent the same feature are physically stored more than once. As an example, note that the item of data in the box labeled with an "x" appears in layer 0, layer 1 and layer 2.

An index for data can be implemented as either homogeneous or non-homogeneous. A homogeneous index appends the control information about related items of data to each indexed item of data. The  $k$ -d-tree structure in Figure 1 is an example of an implementation of a homogeneous index. In the embodiment of Figure 1, appended to each indexed item of data in the database 100 is the control information that indicates the related items of data. A homogeneous index provides advantages with relatively small data sets, e.g., those that fit entirely within a given computer's memory.

A non-homogeneous spatial index maintains the indexing data in a collection of small records that are separate from the indexed items of data. A non-homogeneous index is useful with relatively large data sets, i.e., those that exceed a given computer's memory. A non-homogeneous index has the benefits of being constructed and maintained separate from the indexed objects and of requiring relatively little space.

A homogeneous index and a non-homogeneous may be used together in a single database. A single database can include a non-homogeneous index maintained separate

1 from the data being indexed and can also contain homogeneous index information  
2 appended to items of data.

3 A  $k$ -d-tree index (either homogeneous or non-homogeneous) used with a layered  
4 database works well for many applications. However, there is room for improvement.  
5 For example, it may be desired to provide more granularity, i.e., more layers or ranks of  
6 data. Further, it may be desired to make the indexing structure more flexible. Still  
7 further, it may be desired to index on additional properties of the data or the represented  
8 features.

## 10 SUMMARY OF THE INVENTION

11 To address these and other objectives, the present invention comprises a  
12 multi-dimensional spatial index for data that represent geographic features. The  
13 multi-dimensional spatial index includes at least two dimensions that define physical  
14 boundaries of the geographic features represented by the indexed data. In addition, the  
15 multi-dimensional spatial index includes at least one additional dimension that represents  
16 another property. The other property is an orthogonal, non-spatial property. The other  
17 property may be a property of the geographic features represented by the indexed data or  
18 the other property may be a property of the data. The other property represented by the  
19 additional dimension may include: granularity, distance, altitude, scale bounds within  
20 which each spatial entity is significant, creation date of the data, expiration date of the  
21 data or other property. The multi-dimensional spatial index is applicable to the storage,  
22 retrieval, visualization and traversal of spatial data sets.

## 24 BRIEF DESCRIPTION OF THE DRAWINGS

25 Figure 1 is a diagram illustrating a conventional  $k$ -d-tree structure for geographic  
26 data.

27 Figure 2 is a diagram illustrating a first embodiment of a database for geographic  
28 data with a multi-dimensional index structure having at least three dimensions.

29 Figure 3 is a diagram illustrating a second embodiment of a database for  
30 geographic data with a multi-dimensional index structure having at least three  
31 dimensions.

Figure 4 is a diagram illustrating another embodiment of a database for geographic data with a multi-dimensional index structure having at least three dimensions wherein one of the dimensions is used for layers.

Figure 5 is a diagram illustrating an embodiment of a database for geographic data with a multi-dimensional index structure having at least three dimensions wherein one of the dimensions is used for rank.

Figures 6A-6D show the different ways that a road segment can be displayed at different scales according to the embodiment in Figure 5.

Figures 7A-7D show the different ways that a point of interest or a place can be displayed at different scales according to the embodiment in Figure 5.

## DETAILED DESCRIPTION OF THE PRESENTLY PREFERRED EMBODIMENTS

### I. FIRST EMBODIMENT – GRANULARITY ADDED AS A DIMENSION TO A $k$ -d-TREE INDEX

Figure 2 is a diagram illustrating a first embodiment. In Figure 2, data contained in a geographic database 200 are organized using a multi-dimensional  $k$ -d-tree index having at least three dimensions. Because the multi-dimensional  $k$ -d-tree index is a spatial index, two of the three dimensions are used to index the data spatially. In the multi-dimensional  $k$ -d-tree index in Figure 2, the two dimensions used to index the data spatially define latitude and longitude boundaries for the items of data being indexed.

In addition to the two dimensions used to index the data spatially, the multi-dimensional  $k$ -d-tree in the embodiment of Figure 2 includes at least one more dimension. In addition to the two dimensions used to index the data spatially, the multi-dimensional  $k$ -d-tree in Figure 2 includes a third dimension. The third dimension is used to index another property of the data or of the geographic features being represented. In this embodiment, the third dimension is used as an index for granularity.

In the embodiment of Figure 2, the granularity indexing information in the multi-dimensional  $k$ -d-tree is used to represent three ranks of data. Because rank information is incorporated in the multi-dimensional  $k$ -d-tree in the embodiment of Figure 2, there is no need to provide separate layers of the data, as in the database shown in Figure 1.



Accordingly, a data item which is stored three times in the embodiment of Figure 1 (as shown by the three "x"s) can be stored once in the embodiment shown in Figure 2 (as shown with the one "x").

As mentioned above, an index can be implemented homogeneously or non-homogeneously. In the embodiment of Figure 2, the multi-dimensional  $k$ -d-tree index is implemented homogeneously, i.e., the indexing information is appended to the data items being indexed.

The granularity indexing information used to represent three ranks of data in the multi-dimensional  $k$ -d-tree in the embodiment of Figure 2 is not restricted to integer values of rank (i.e., 0, 1, 2, etc.), but may have non-integer values as well (e.g., 0-0.99, 1.00-1.99, 2.00-2.99, etc.). Thus, the multi-dimensional  $k$ -d-tree index allows a continuous range of rank values, and therefore greater granularity.

In the embodiment of the multi-dimensional  $k$ -d-tree index in Figure 2, two dimensions are used for spatial organization and one dimension is used for granularity for a total of three dimensions. Alternatively, the data set 200 can be implemented using a six-dimensional  $k$ -d-tree. According to this alternative, the six dimensions include four dimensions used for spatial indexing plus two dimensions for the granularity. The four dimensions used for spatial indexing correspond to the boundaries (i.e., minimum latitude, minimum longitude, maximum latitude, and maximum longitude) for each two-dimensional item of data being indexed (i.e., for a rectangular area, its four physical bounds). The two additional dimensions, which are used for the granularity property, can be used to define granularity ranges for each item of data being indexed (e.g., 0-0.99, 1.00-1.99, 2.00-2.99, etc.)

In the embodiment of Figure 2, the multi-dimensional index includes than three dimensions. In alternative embodiments, the multi-dimensional index may include more than three dimensions. According to alternative embodiments, the multi-dimensional index can include four or more than dimensions. According to these alternative embodiments, two dimensions of the four or more dimensions are used for spatial indexing of the data items being indexed. The other two or more dimensions are used for indexing the items of data with respect to additional properties of the data or the represented geographic features.

II. SECOND EMBODIMENT – GRANULARITY ADDED  
AS A DIMENSION TO A NON-HOMOGENEOUS  $k$ -d-TREE

Figure 3 shows another embodiment of a multi-dimensional  $k$ -d-tree index that has at least three dimensions and which is used for indexing data that represent geographic features. In Figure 3, a database 300 for geographic data uses a multi-dimensional  $k$ -d-tree index 310. As stated in the Background, an index can be implemented as either homogeneous or non-homogeneous. In the embodiment of Figure 3, the multi-dimensional  $k$ -d-tree index 310 is implemented as a non-homogeneous index. Accordingly, the multi-dimensional  $k$ -d-tree index 310 is maintained separate from the items of data 320 being indexed.

Like the homogeneous multi-dimensional  $k$ -d-tree index described in Figure 2, the non-homogeneous multi-dimensional  $k$ -d-tree index 310 in Figure 3 is a spatial index. Therefore, two of the three dimensions of the non-homogeneous multi-dimensional  $k$ -d-tree index 310 are used for spatially indexing the data 320. In addition to the two dimensions used to index the data spatially, the multi-dimensional  $k$ -d-tree index 320 in the embodiment of Figure 3 includes at least one more dimension. In this embodiment, the additional dimension is used as an index for granularity.

Like the multi-dimensional  $k$ -d-tree index in Figure 2, the multi-dimensional  $k$ -d-tree index 310 in Figure 3 can be implemented using six-dimensions, i.e., four dimensions for spatial indexing plus two dimensions for granularity.

III. ALTERNATIVE EMBODIMENTS

A. OTHER PROPERTIES ADDED AS A DIMENSION  
 TO A NON-HOMOGENEOUS  $k$ -d-TREE

In the embodiments described in Figures 2 and 3, the additional property included as a dimension in the multi-dimensional  $k$ -d-tree index was granularity. Granularity is not the only property that can be used as the additional dimension. Instead of granularity, the additional dimension included in the multi-dimensional  $k$ -d-tree index can include any other property of the data. Some of the other properties include the following:

- (1) distance,
- (2) altitude,

- (3) scale,
- (4) rank bounds within which it is contained or significant,
- (5) expiration date, and
- (6) creation date.

“Altitude” as a property refers to the altitude from which a map generated from the data is viewed. For example, for map views representing 10 – 70 meters altitude, certain data representing geographic features are used. For map views representing 71- 200 meters altitude, certain other data are used.

“Scale” as a property refers to the map scale used by the map display application that uses the data. At a scale of 1:5000, certain data are used to represent geographic features. At a scale of 1:10,000, other data are used to represent the geographic features.

As items (5) and (6) in the above list indicate, the additional property that is added as a dimension does not have to possess a spatial quality *per se*.

#### B. ALTITUDE ADDED AS A SPATIAL DIMENSION TO A MULTI-DIMENSIONAL $k$ -d-TREE

In the embodiments described in Figures 2 and 3, two dimensions of the multi-dimensional  $k$ -d-tree index are used for spatially indexing the data contained in the geographic database. The two dimensions used for spatial indexing define the latitude and longitude boundaries of the represented features. In an alternative embodiment, the spatial dimensions may also include the altitude of the geographic feature represented by the item of data being indexed. In this alternative, three dimensions of the multi-dimensional  $k$ -d-tree index are used for spatially indexing the data contained in the geographic database and an additional dimension, i.e., a fourth dimension, is included for indexing the data based upon another property of the data or the geographic data represented by the data.

According to one of the alternatives described above, a multi-dimensional  $k$ -d-tree is disclosed that has at least six dimensions. According to that alternative, two dimensions are used for each spatial direction (i.e., two for latitude and two for longitude) so that four dimensions are used for spatially indexing the geographic data. In that alternative, the multi-dimensional  $k$ -d-tree includes at least two additional dimensions

1 which are used for indexing the data based upon another property, e.g., granularity. If  
2 altitude is included as a spatial dimension and if two dimensions are used for each spatial  
3 direction, an alternative embodiment of a multi-dimensional  $k$ -d-tree has at least eight  
4 dimensions. In this alternative, six dimensions are used for spatial indexing (two for  
5 latitude, two for longitude and two for altitude). In addition to these six dimensions, the  
6 multi-dimensional  $k$ -d-tree includes at least two additional dimensions. These additional  
7 dimensions are used for indexing the data based upon a property of the data other than  
8 latitude, longitude or altitude of the represented feature, e.g., granularity.

#### 10 C. OTHER ALTERNATIVES

11 As mentioned above, the multi-dimensional  $k$ -d-tree index can be implemented as  
12 either homogeneous (as in Figure 2) or non-homogeneous (as in Figure 3). The multi-  
13 dimensional  $k$ -d-tree index may be implemented as a homogeneous index for small,  
14 malleable data sets. The multi-dimensional  $k$ -d-tree index may be implemented as non-  
15 homogeneous for larger or constant data sets stored on magnetic media or CD-ROM.

16 In the previously described embodiments, the multi-dimensional index is  
17 implemented using a  $k$ -d-tree structure. In alternative embodiments, the multi-  
18 dimensional index may have a structure other than a  $k$ -d-tree. As an example, for the  
19 multi-dimensional index may have a different hierarchical data structure, such as those  
20 from the field of solid modeling, as described by Hanan Samet in *The Design and*  
21 *Analysis of Spatial Data Structures*, Addison-Wesley, Reading, MA, 1990, Chapter 5.

22 In the embodiments described above, one additional property is indexed in the  
23 multi-dimensional  $k$ -d-tree in addition to the spatial dimensions. In alternative  
24 embodiments, the multi-dimensional  $k$ -d-tree can include dimensions for more than one  
25 additional property. For example, a four dimensional  $k$ -d-tree can be used for indexing  
26 latitude, longitude, granularity and expiration date of the represented data items.

#### 28 IV. APPLICATIONS

29 This section presents examples to illustrate applications in which the advantages  
30 of the disclosed embodiments can be realized.

### A. Map Storage

The embodiments of the multi-dimensional  $k$ -d-tree index, described above, allow infinite granularity within a single spatial data file (subject to the number of bits of resolution allocated to representing the granularity). Only a small percentage of entities in a data set are relevant at the highest layer, however, every entity in a spatial data set is relevant at the lowest layer.

Figure 4 depicts a database 400 containing geographic data 420. The geographic data 420 includes three layers of granularity formed by three layers 422, 424, and 426 stored in a single file. A single non-homogeneous multi-dimensional  $k$ -d- tree spatial index 410 is used to access the data 420. If a conventional  $k$ -d-tree index were used, the same spatial data set would have required three two-dimensional spatial indices and stored in three progressively larger data files – each duplicating the higher layers' data.

Although three layers 422, 424, and 426 are shown in the embodiment of Figure 4, alternative embodiments may include more or fewer layers. In addition, the layers are not constrained to integer values but may assume a continuous range of values.

### B. Map Rendering

The embodiments of the multi-dimensional  $k$ -d-tree index, described above, allow precise control over the range of scales at which spatial entities are visualized. Each cartographic feature can possess a specific range of scales at which it is to be visualized. A minor feature might, because of its prominence or location, be visualized at uncharacteristically large map scales. By contrast, with conventional indexing schemes, cartographic features are visualized depending on broad, general criteria.

### C. Navigation routing

The embodiments of the multi-dimensional  $k$ -d-tree index, described above, allow for several rank-dependent representations of a navigable road segment, not just in a single spatial index but in a single navigable data set as well. High-ranking roads, for example, might be aggregated into progressively simpler representations as lower-

ranking intersections are dropped. At a highest rank, a stretch of highway might be represented as a single line between two major junctions. At a lowest rank, the same stretch of highway might be represented as a string of shorter segments connecting the intersections that lie between the two major junctions.

Figure 5 depicts a geographic database 500 including data 520 stored with three ranks of granularity, 522, 524, and 526. A single non-homogeneous, multi-dimensional  $k$ -d-tree index 520 is used to access the data 520. (Although three ranks are shown, the multi-dimensional  $k$ -d-tree index allows a continuous range of rank values.) By contrast, with prior indexing schemes, the same data would have required three two-dimensional spatial indices and three somewhat redundant, progressively smaller rank files.

## V. REPRESENTATION OF SPATIAL ENTITIES

Embodiments of the multi-dimensional  $k$ -d-tree index, described above, allow for several scale-dependent representations of an entity within a single spatial index. A divided highway, for example, might have a different representation for each of the map scales at which the data can be viewed. Figures 6A-6D depict four representations of a divided highway viewed at different map scales. (Although four map scales are suggested, embodiments of the multi-dimensional  $k$ -d-tree index allow for a continuous range of map scale values.) With prior indexing schemes, a separate two-dimensional index (and possibly a separate data set) would be required to distinguish each of the four representations.

Embodiments of the multi-dimensional  $k$ -d-tree index, described above, facilitate distance-dependent representations of a three-dimensional entity within a single spatial index. A sphere, for example, might be represented by tessellated polygons of increasing complexity depending on the distances from which it is viewed. Figures 7A-7D depict representations of varying complexity for a single three-dimensional sphere viewed from various distances.

1 VII. ADVANTAGES

2 Several advantages follow from embodiments of the disclosed systems.

3  
4 A. Allows continuous rather than stepped granularity.

5 Prior indexing techniques organized spatial data into stepped planes of decreasing  
6 granularity (e.g., layers 0, 1, 2 . . .  $n$ ). The disclosed embodiments index spatial data  
7 according to their granularity as well as their physical dimensions, and therefore the  
8 granularity values are allowed to fall more precisely within a continuous range rather  
9 than a series of steps. For example, a road segment can have a rank of 1.375. A graphic  
10 of the road segment can be visualized at map scales up to exactly 1:9,056. A navigable  
11 road segment, on the other hand, can fall within a range of (possibly fractional) rank  
12 values.

13  
14 B. Eliminates the need to parcelize spatial  
15 data into separate but coincident "layer" files.

16 Conventional indexing techniques require a spatial data set to be distributed  
17 among a series of "layer" files, each containing the data relevant to a certain degree of  
18 granularity (less granular data is often replicated among several, possibly all, layers).  
19 Each layer file then indexes its spatial entities using a traditional two-dimensional spatial  
20 index according to their minimum bounding rectangles:  $\min_x$ ,  $\min_y$ ,  $\max_x$ , and  $\max_y$ .  
21 The third dimension can further index spatial data by  $\min_z$  and  $\max_z$  values indicating  
22 their bounding layers, eliminating the need to parcel a spatial data set into layers of  
23 various granularities.

24  
25 C. Allows a single spatial data set to be visualized at any granularity.

26 Visual displays of two-dimensional spatial data face the same granularity issues  
27 as the physical storage format. Certain types of spatial entities (points of interest, local  
28 streets) lose their significance at higher map scales. Linear or polygonal graphics shrink  
29 to invisibility at higher map scales. The third dimension afforded by the Invention can

1 further index spatial data by  $\min_z$  and  $\max_z$  values indicating the minimum and  
2 maximum altitudes or map scales within which each spatial entity should be visualized.

- 3  
4 D. Allows multiple scale-dependent representations  
5 of a spatial entity in a single collection of graphics.

6 Visual displays of two-dimensional spatial data often use one of several different  
7 graphics to represent a spatial entity, depending on the scale or altitude at which the data  
8 is visualized. The third dimension afforded by the multi-dimensional  $k$ -d-tree index can  
9 index the minimum and maximum altitudes or map scales at which to display each  
10 graphic representation, allowing a single collection of graphics to distinguish among  
11 several scale-dependent representations of a spatial entity.

- 12  
13 E. Eliminates the need to parcel navigable data into  
14 separate but coincident "rank" files, and allows multiple  
15 rank-dependent representations of a navigable entity.

16 Navigation databases face the same granularity issue as physical storage formats  
17 and visualization. Like the "layer" sets into which a spatial data set is often parceled,  
18 navigation data sets are parceled into separate "rank" sets, each containing the data  
19 significant at a certain granularity or level of functionality. Like graphics collections,  
20 each navigation data set may use multiple rank-dependent representations of a navigable  
21 entity. At the lowest rank (most granular), an arterial road might consist of a number of  
22 connected segments joined at side-street intersections. At higher ranks (less granular),  
23 the arterial road might be aggregated into a single segment connecting other arterial  
24 roads. At the highest rank (least granular), the arterial road might not even be  
25 represented. Embodiments of the disclosed multi-dimensional index includes a third  
26 dimension that facilitates indexing navigable entities by minimum and maximum rank,  
27 allowing a single navigable data set to distinguish among several rank-dependent  
28 representations of each navigable entity. Embodiments of the disclosed multi-  
29 dimensional index also eliminate duplication of entities (points of interest, higher-rank  
30 intersections) that are shared among ranks.



- 1           It is intended that the foregoing detailed description be regarded as illustrative
- 2   rather than limiting and that it is understood that the following claims including all
- 3   equivalents are intended to define the scope of the invention.

1 WE CLAIM:

1 1. An improved index for data that represent geographic features, wherein  
2 said index has a structure that includes two spatial dimensions whereby said data indexed  
3 by said structure are searchable spatially using said two spatial dimensions, the  
4 improvement comprising:

5 an additional dimension included in said structure of said index, whereby a  
6 property of the geographic features represented by the data is searchable using said  
7 additional dimension.  
8

1 2. An improved index for data that represent geographic features, wherein  
2 said index has a structure that includes two spatial dimensions whereby said data indexed  
3 by said structure are searchable spatially using said two spatial dimensions, the  
4 improvement comprising:

5 an additional dimension included in said structure of said index, whereby a  
6 property of the data that represent the geographic features is searchable using said  
7 additional dimension.  
8

1 3. The invention of Claim 1 or 2 wherein said structure is a  $k$ -d-tree index  
2 structure comprising a root node, intermediate nodes and leaf nodes, wherein each node  
3 is part of a parent-child relationship wherein each parent node includes control  
4 information from which one of at least two child nodes associated with the parent node  
5 are distinguishable based on a search key.  
6

1 4. The invention of Claim 1 or 2 wherein said improved index is  
2 homogeneous.  
3

1 5. The invention of Claim 1 or 2 wherein said improved index is  
2 non-homogeneous.  
3

1 6. The invention of Claim 1 or 2 wherein said geographic features are roads.  
2

1           7.     The invention of Claim 1 wherein said property is a rank of the geographic  
2 features represented by the indexed data.  
3

1           8.     The invention of Claim 7 wherein said rank includes both integers and  
2 fractional values.  
3

1           9.     The invention of Claim 2 wherein said property is a granularity of the  
2 indexed data.  
3

1           10.    The invention of Claim 2 wherein said property is a viewing altitude  
2 associated with the indexed data.  
3

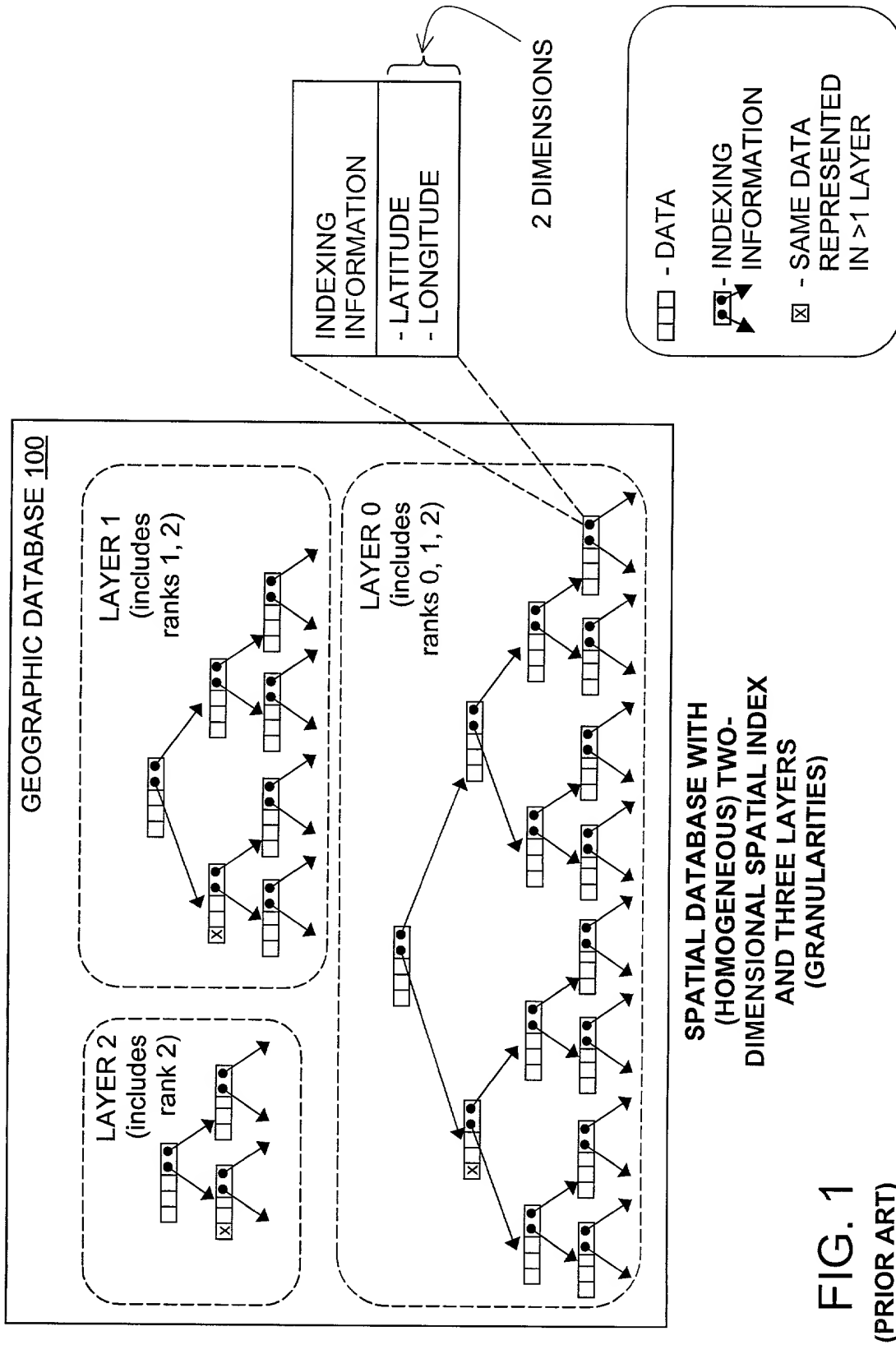
1           11.    The invention of Claim 2 wherein said property is a scale associated with  
2 the indexed data.  
3

1           12.    The invention of Claim 2 wherein said property is an expiration date  
2 associated with the indexed data.  
3

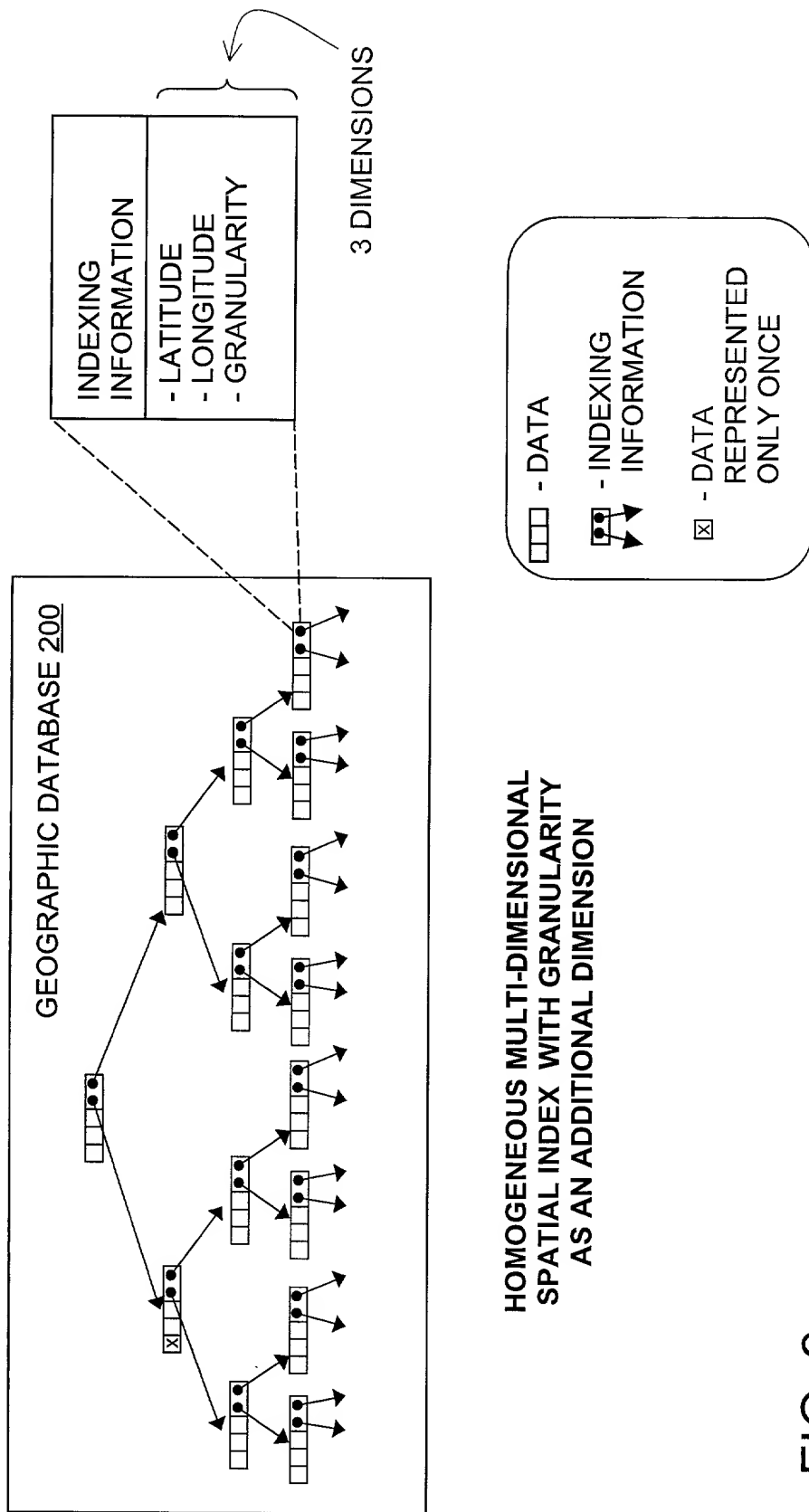
1           13.    The invention of Claim 2 wherein said property is a creation date  
2 associated with the indexed data.  
3

## ABSTRACT

A multi-dimensional spatial index includes at least two dimensions that define physical boundaries of the features represented by the indexed data. In addition, the multi-dimensional spatial index includes at least one additional dimension that represents another property. The other property is an orthogonal, non-spatial property. The other property may be a property of the features represented by the indexed data or the other property may be a property of the data. The other property represented by the additional dimension may include: granularity, distance, altitude, scale bounds within which each spatial entity is significant, or other property. The multi-dimensional spatial index is applicable to the storage, retrieval, visualization and traversal of spatial data sets.

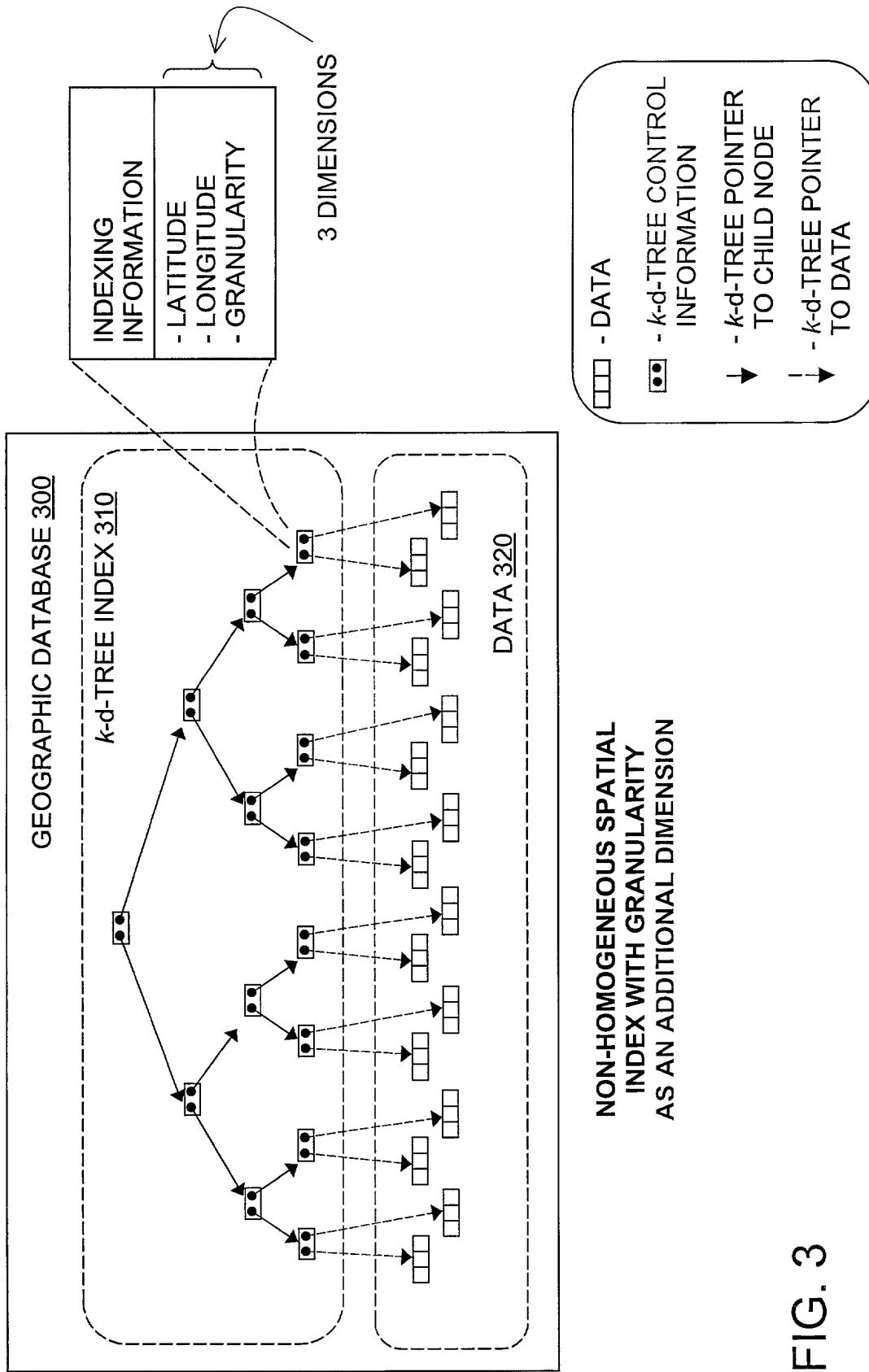


**FIG. 1**  
(PRIOR ART)



HOMOGENEOUS MULTI-DIMENSIONAL  
SPATIAL INDEX WITH GRANULARITY  
AS AN ADDITIONAL DIMENSION

FIG. 2



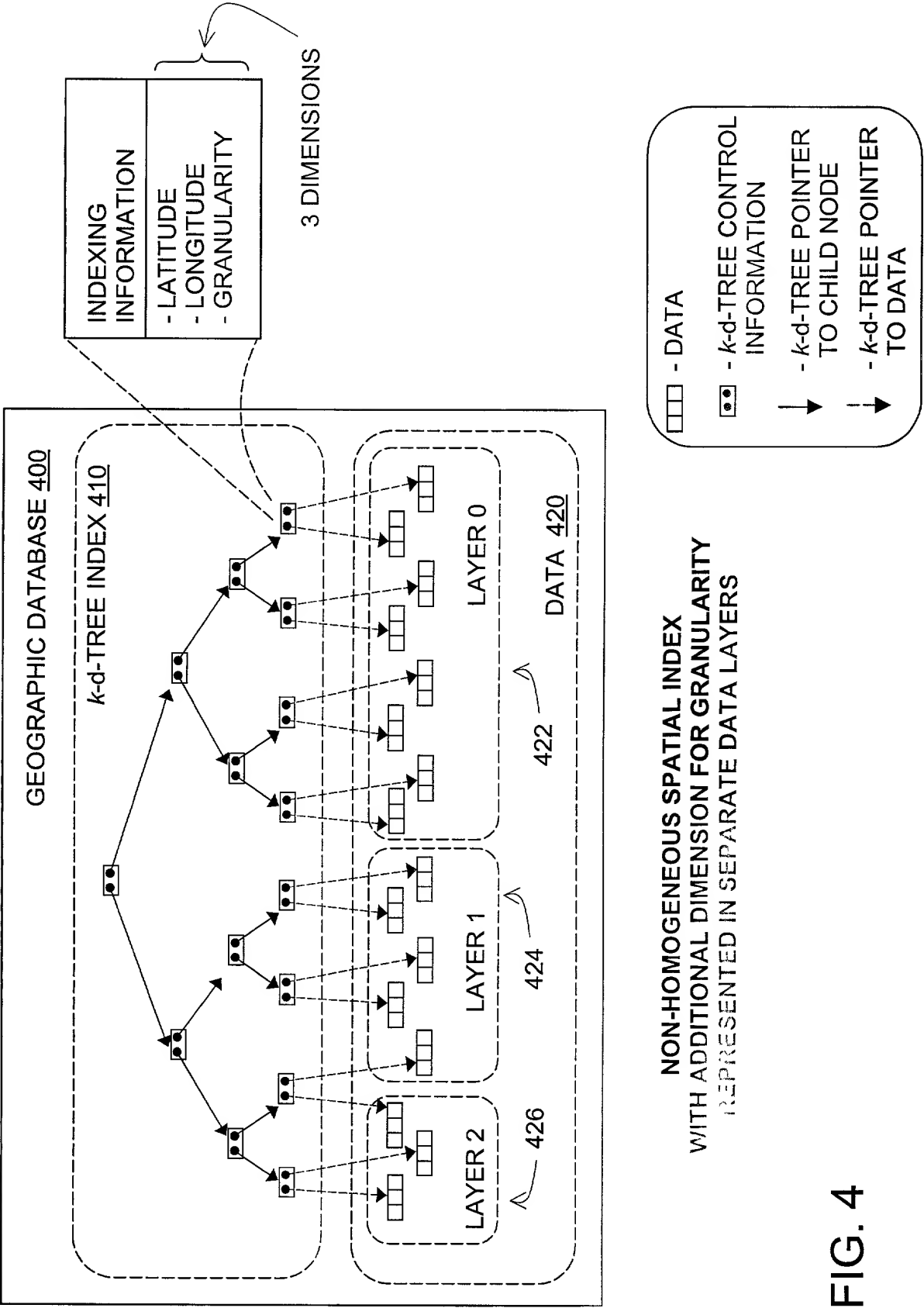
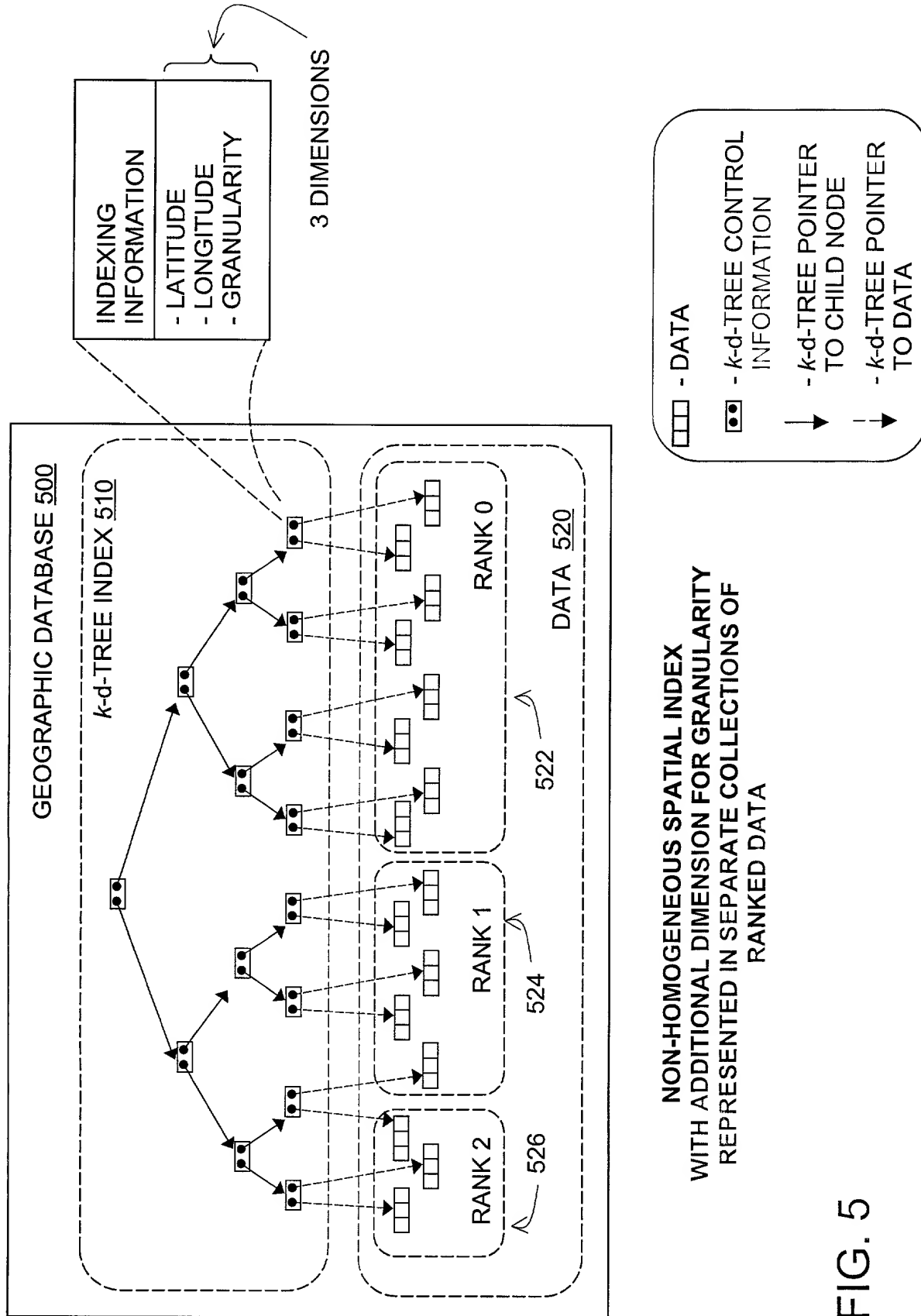


FIG. 4





SCALE-DEPENDENT REPRESENTATIONS OF A  
SPATIAL ENTITY

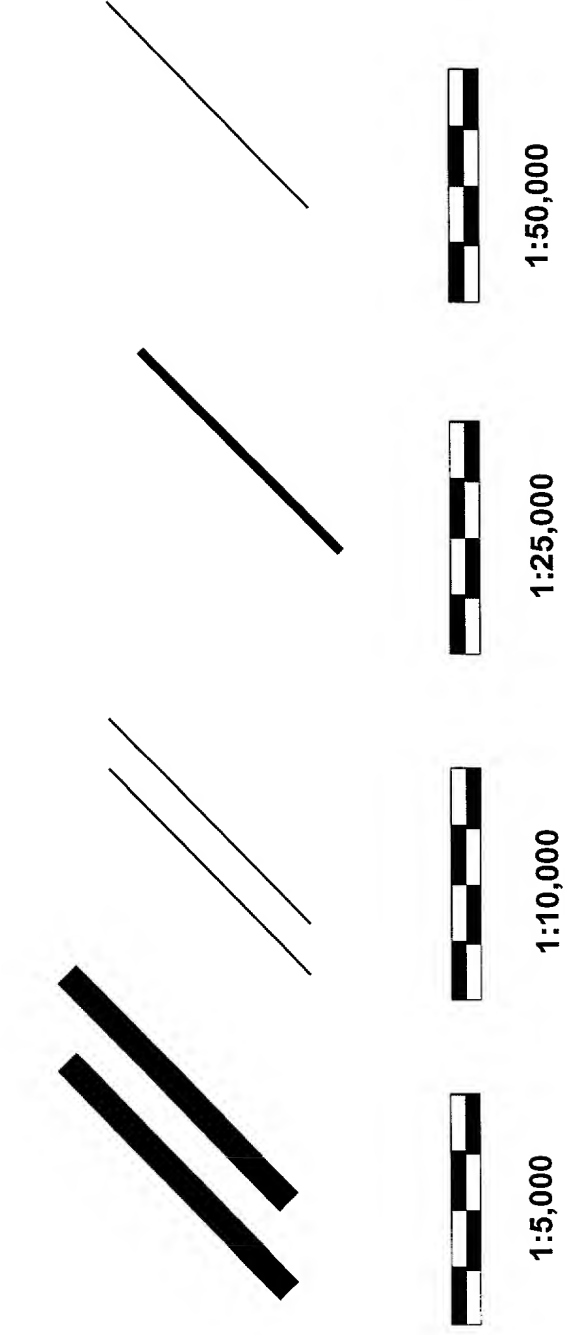


FIG. 6A

FIG. 6B

FIG. 6C

FIG. 6D

DISTANCE-DEPENDENT  
REPRESENTATIONS OF A SPATIAL  
ENTITY

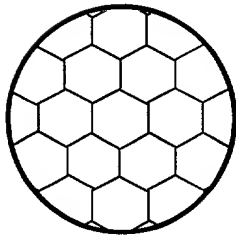


FIG. 7A

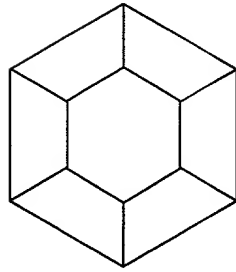


FIG. 7B

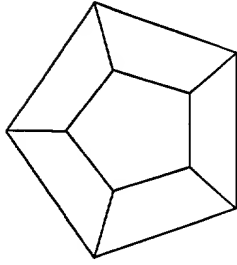


FIG. 7C

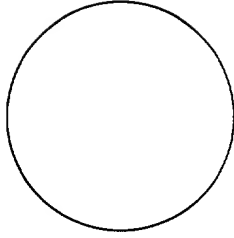


FIG. 7D

10,000 M

50,000 M

100,000 M

**DECLARATION FOR PATENT APPLICATION**

As a below named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below next to my name.

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled, entitled MULTI-DIMENSIONAL SPATIAL INDEX FOR A GEOGRAPHIC DATABASE, the specification of which:

- ☒ is attached hereto.
- ☐ was filed on \_\_\_\_\_ as Application Serial No. \_\_\_\_\_.
- ☐ and was amended on \_\_\_\_\_ (if applicable).

I hereby state that I have reviewed and understand the contents of the above-identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose information which is material to the patentability as defined in Title 37, Code of Federal Regulations, § 1.56(a).

I hereby claim foreign priority benefits under 35 U.S.C. § 119(a)-(d) or § 365(b) of any foreign application(s) for patent or inventor's certificate or § 365(a) of any PCT International application which designated at least one country other than the United States, listed below and have also identified below, by checking the box, any foreign application for patent or inventor's certificate, or PCT International application having a filing date before that of the application on which priority is claimed:

<u>Prior Foreign Application(s)</u>			<u>Priority Claimed</u>	
_____	_____	_____	<input type="checkbox"/>	<input type="checkbox"/>
(Number)	(Country)	(Day/Month/Year Filed)	Yes	No

I hereby claim the benefit under 35 U.S.C. § 119(e) of any United States provisional application(s) listed below:

_____	_____
(Application Serial No.)	(Filing Date)

I hereby claim the benefit under 35 U.S.C. § 120 of any United States application(s), or § 365(c) of any PCT International application designating the United States, listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States or PCT International application in the manner provided by the first paragraph of 35 U.S.C. § 112, I acknowledge the duty to disclose information which is material to patentability as defined in 37 CFR § 1.56 which became available between the filing date of the prior application and the national or PCT International filing date of this application:

_____	_____	None
(Application Serial No.)	(Filing Date)	(Status-patented, pending, abandoned)

As a named inventor, I hereby appoint the following registered practitioners to prosecute said patent application and to transact all business in the Patent and Trademark Office connected therewith:

Frank J. Kozak (Reg. No. 32,908)  
Lawrence M. Kaplan (Reg. No. 33,521)

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fax: (847) 699-8057

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

Inventor's Signature

Full name of sole or first inventor

Residence

Citizenship

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Date:

*6 Nov 2000*

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Date:

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rev. Feb. 1999